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## CANADIAN PATENT

LINER EXPANDER

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Granted to Pan American Petroleum Corporation, Tulsa, Oklahoma, U.S.A.

APPLICATION No. 897, 460

PRIORITY DATE

No. OF CLAIMS

#### LINER EXPANDER

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This invention relates to a constant force spring device, and more particularly, to a device for expanding a metallic liner wherein an expanding die is urged against the liner by a constant force spring device.

Heretofore, a method and apparatus have been developed for installing an expanded metallic liner in an oil well or other conduit. Typically, a corrugated steel liner is inserted in a conduit which is to be lined, the greatest peripheral dimension of the liner being slightly less than the inside diameter of the conduit. An expanding tool is passed through the liner placed in the conduit, and a first-stage expanding die causes a gross plastic deformation of the liner, which is expanded outwardly against the inside of the conduit. A second-stage die on the tool then provides an additional finer deformation of the liner to provide a smoother, more finished surface on the inside of the liner and to assure more complete contact between the conduit and the liner. In a typical design of this type expanding tool, the frictional drag of the first-stage die supplies the expanding force for the second-stage die, which expanding force is a direct function of the strength, or wall thickness, of the conduit in which the liner is being installed. For example, in lining oil well casing, heavy wall casing may cause a very high frictional force which results in excessive pressure being required to push the expander through the liner. The application of the great forces required may result in rupture of the casing or in breaking the installing tool. In instances where the internal diameter of the conduit is somewhat less than that anticipated, the resulting forces can cause the tool to become stuck in the casing, or otherwise cause damage to the casing and the tool. In other designs, such as where a cantilever spring arrangement is employed in connection with the secondstage die, various difficulties are encountered in obtaining a spring mechanism having the desired strength in combination with the other spring characteristics, and with the tool dragging against the inside wall of the conduit after being passed through the liner.

Since tools of the type mentioned above often are employed in wells deep in the ground, it is highly preferable that a tool be used which under no circumstances will become stuck in the well or cause damage to the well. Any such trouble occurring in a well can result in considerable loss in time and great expense in making repairs.

An object of the present invention is a device for applying a constant force to an expanding die or other similar apparatus so that a preselected maximum force is exerted against a work piece. Another object is an improved expanding tool for installing metallic liners in a conduit, which expanding tool can apply no greater than a predetermined force to the liner being installed in the conduit. Still another object of the invention is an economical and easily fabricated constant force spring device. A further object is a rugged, easy-to-operate expanding tool employing such a spring device. These and other objects of the invention will become apparent by reference to the following description of the invention.

In accordance with the present invention there is provided a constant force spring device which comprises a body member, an elongated column element adjacent said body member, bearing plate members contacting the two ends of said column at least one of said bearing plate members being longitudinally movable in respect of the other and stop means on said body member to limit the deflection of said column element to prevent permanent deformation of said column element upon the application of a compressive load thereto. In one embodiment of the invention, the foregoing constant force spring device is employed in a tool for expanding a metallic liner inside a conduit, said constant force spring device being positioned on said tool to urge an expanding die member against the liner being installed in the conduit by a substantially constant force.

My invention will be better understood by reference to the following description and the accompanying drawings wherein:

Figures 1A, 1B and 1C, taken together, constitute a partial sectional view of a preferred embodiment of a liner expanding tool according to the present invention; and

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Figure 2 is a sectional view of the apparatus of Figure 1A taken at line 2-2; and

Figure 3 is a typical plot of applied Load versus Deflection for the constant force spring device of the invention.

Referring to the drawings, Figure 1A is the bottom portion of a liner expanding tool for use in installing a metallic liner in a well, while Figure 1B illustrates the middle section of such a tool and Figure 1C represents the upper section of the tool. The expanding tool ll is attached to standard well tubing 12 by coupling 13 and, typically, may be lowered from the surface through a well casing (not shown) to a point in the casing at which it is desired to install a metallic liner. Before inserting the tool into the well, an elongated vertically corrugated liner 14 fabricated from mild steel, or other suitable malleable material, is placed on the tool. The corrugated liner is secured in position by contact at its upper end with a cylindrical shoulder member 16 and, at its lower end by contact with a first-stage expanding die 17 in the form of a truncated circular cone which serves as a firststage expanding die in the manner hereinafter described. The expanding die is fixedly attached to a centrally located, elongated cylindrical hollow shaft 18 which forms a portion of the body of the tool. As shown, the expanding die 17 is held in place between a lower shoulder 19 and collar 21 threaded onto the shaft. A plurality of movable arms 22, preferably provided with outwardly enlarged portions 23 near the top, are disposed in the form of a cylinder around shaft 18. The enlarged portions of the arms 23 upon being moved outwardly contact the liner to perform the final step of expanding the corrugated liner into a substantially cylindrical shape. The arm members 22 are pivotally attached to the shaft so as to be movable outwardly from the shaft by a tapered expanding member 24 slidably positioned on the shaft to serve as a second-stage expander. The surface of the member 24, as shown, moves upwardly along the shaft to engage with the arms and move them outwardly. Advantageously, the inside surfaces of the arms 22 and the outside surface of expanding member 24 form mating sections, typically octagonal in shape. The expansion of the arm members is controlled by the position of the member 24 which moves upwardly

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until it contacts shoulder 26 provided on the shaft. As member 24 moves in a downwardly direction arms 22 fold inwardly toward the shaft. The expanding arms 22 are held in place on the shaft by collar 27 and circular groove 28 provided on the shaft.

The expanding tool, comprising the first-stage die and the secondstage die is drawn through the liner to expand it in place in the casing. The first-stage die provides a gross deformation of the liner so that it is expanded outwardly against the wall of the casing. The second-stage die then passes through the liner and performs the final expansion to smooth the inner surface of the liner and to provide more even contact between the liner and the wall of the casing and effect a fluid-tight seal.

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In operation, the liner setting tool is assembled at the surface, as described above, and a glass cloth saturated with a resinous material may be wrapped around the corrugated tube to form the liner. The assembly is lowered into the well at the location at which the liner is to be set. A liquid, such as oil, is then pumped under pressure down the well tubing and flows through the passageway 29 provided in polished rod 31, through ports 32 and into cylinder 35 connected to the upper end of the shoulder 16. Upon the application of fluid pressure to the cylinder, the piston 34 secured to polished rod 31 moves upwardly in cylinder 33. As shown, rod 36 connects polished rod 31 and shaft 18 upon which is mounted the first-stage expanding die 17. When the piston 34 moves upwardly through the cylinder 33 the expanding die 17 and the secondstage die 22 are drawn upwardly into the corrugated liner 14 and "iron out" the corrugations in the liner, so that the expanded liner may contact the inside wall of the casing in which it is being installed. Positioned on the shaft below the expanding member 24 is a constant force spring member 37 which is employed to urge the expanding member against the expanding arms 22 with a substantially constant force. The force exerted against the arm members being substantially constant, the force transmitted through the arm members to the liner and to the casing will be substantially constant so that either sticking of the tool in the casing or rupture of the casing is precluded. Of course, the force provided by the spring member is preselected so that the frictional

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forces between the tool and the liner and the pressure exerted against the casing are maintained at predetermined safe levels. The constant force spring member assures that the contact pressure between the liner forming portion 23 of the arms 22 is great enough to provide the desired deformation of the casing, while preventing damage to the casing or to the tool.

The constant force spring member 37 is slidably mounted on the shaft 18 and held between the expanding element 24 and a cylindrical lower shoulder member 38 forming a portion of a differential sorew element 39 which transmits the loading on spring member 37 to shaft member 18. The differential screw element comprises shaft member 18 on the outside of which are cut male threads 18a, the lower shoulder member 38 provided with female threads 38a and thimble member 41 provided with threads 41a and 41b on the outside and the inside, respectively, to engage with threads on the shaft and the shoulder. The two sets of threads are coarse, such as square, modified square, or Acme threads, to withstand very high loads and differ in pitch so that shoulder 38 is moved upwardly on the shaft 18 when the shaft is revolved relative to thimble 41. The shoulder 38 is secured to the shaft 18 by splines 45 so that it can slide longitudinally, but it is not free to rotate on the shaft. Fixedly attached to the lower end of the thimble is a friction member, such as bow springs 42, a hydraulically actuated friction pad, or other such device for frictionally engaging with the inside wall of the conduit to secure the thimble against rotation with respect to the shaft. Preferably, the direction of the shoulder member threads 38a is the same as that of the shaft threads 18a, e.g. righthand threads, and the pitch, or lead, of threads 18a is slightly greater than that of threads 38a, with the pitch ratio being close to unity. In this manner, clock-wise revolution of the shaft relative to the thimble causes shoulder member 38 to advance upward slightly and a compression load is exerted upwardly on spring element 37 to cause buckling. For example, one satisfactory differential screw was made up using five and one-half threads/inch square threads on a shaft approximately 1.7-inch outside diameter and five and threequarters threads/inch square threads on a shoulder approximately 2.5-inches inside diameter.

Constant force spring element 37 comprises column element 43, advantageously consisting of a plurality of elongated columns disposed around shaft 18. Upper bearing plate member 44 is in contact with the upper ends of the columns and is slidably positioned on shaft 18 to transmit the force of the spring longitudinally against the bottom end of expander member 24. Lower bearing plate member 46 contacts the lower ends of the columns and is moved upwardly along the shaft by longitudinal movement of lower shoulder 38 as a result of revolving differential screw element 39. Grooves 47 are provided in each of the bearing plates, to form an upper race and a lower race, into which the ends of the columns are inserted. These grooves may be shaped to conform with the shape of the column ends if desired. A cover 48 may be employed to exclude foreign matter from the spring mechanism and to protect the spring.

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A means for limiting the deflection of the columns is required. Although the column element functions in a buckled condition, application of excessive compressive load thereto would cause total failure or rupture of the columns. Therefore, a pair of stops 49 and 49a are provided for this purpose. As shown, the stops are rigidly connected to the bearing plates, and, in effect comprise upper and lower limiting sleeves positioned on the shaft to slide longitudinally thereon. The ends of the stops may move toward, or away from, each other as the load on the spring member varies. Lover sleeve 49a is prevented from moving down by lower shoulder 38 connected to the shaft 18. However, the spacing between the ends is such as to limit the longitudinal travel of the bearing plate members as they move together to prevent permanent deformation of the column element 43. Various alternative means for preventing damage to the column element may also be employed. For example, pins or rings mounted on the shaft may serve as stops, or the cover 48 provided with suitable connections may be employed for this purpose to limit longitudinal and/or lateral deflection of columns.

The columns of the column element 43 may be arranged around the shaft 18, which as shown here forms a portion of the body of the spring device, with ends of the columns fitted in the races 47. The columns may be

fitted closely together as shown, or may be spaced around the race, with separators used between them to maintain the desired spacing. The number of columns employed will depend upon column characteristics and the materials of construction. For example, the slenderness ratio of the column may be varied widely, and the column ends may be round, flat, fixed or hinged. The preferred construction is a thin, slender column with rounded ends, free to move within the races shaped to the curvature of the column ends. Materials which may be satisfactorily employed for the columns are carbon and low alloy steels, chromium and nickel-chromium stainless steels, various copper base alloys, such 10 as phosphor bronze, beryllium copper, the high nickel alloys and other similar materials providing satisfactory mechanical properties. Typically, the individual columns are of long rectangular cross-section, with the width being greater than the thickness, and arranged so that the wider face of the columns is normal to the diameter of the shaft. Thus, with sufficient compression loading, the columns buckle, and bend about the axis having the least moment of inertia, e.g., outwardly away from the shaft lo.

For example, a group of columns 0.167-inch thick by 0.438-inch wide by 10.626-inches long, with the ends rounded, were fabricated from A.I.S.I 4340 steel, quenched and drawn at 575°F. Each column was found to require a 20 critical compression loading of 450 rounds in order to buckle the column. After buckling, the columns were found to have a very flat spring characteristic, as shown in Figure 3, wherein  $P_{\rm c}$  is the critical buckling load and point C represents the load and deflection at which the stress in the extreme fibers of the column exceed the yield point of the material. Theoretically, the shape of this spring characteristic curve is described by curve OA'ABC. Actually, this curve is described by OABC due to friction in the system. Points A end B represent typical working limits, which, of course, may be varied according to the application for which the spring is designed. For example, where a large number of flexing cycles are not anticipated, a working stress just below the 30 yield point may be used, while with a great number of flexures, the working stress may be held to less than the endurance limit of the material of construction. In the above-mentioned tests, the lateral deflection was limited to

approximately one inch, at which the longitudinal deflection was approximately: 0.225 inches. From zero deflection to the maximum deflection, the 450-pound loading was found to be substantially constant.

In another test a spring device was built, as shown, employing 20 columns, each having a critical buckling load of 1250 pounds. The lateral deflection was limited between 0 and about 1.00 inches by appropriately positioning the stops. Upon compressional loading, the spring element buckled at substantially 25,000 pounds and from a longitudinal deflection of 0.04 inches (buckling) to about 0.15 inches the load remained substantially at 25,000 pounds.

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Of course, in designing a spring element as above it is advantageous to obtain the greatest possible value of longitudinal deflection for specified values of lateral deflection and critical buckling load, while maintaining the stress level in the columns at a safe level. The preferred columns, therefore, are laminated, as shown in Figures 1B and 2, with multiple flat members making up each column.

In the operation of the above expanding tool for setting a liner in well casing, the made-up tool is lowered into the well as mentioned above, with the arms 22 in the retracted position. When the tool is at the desired level, the well tubing is revolved. The friction member \$2\$ engages with the wall of the casing and prevents thimble \$1\$ from revolving. With several revolutions of the tubing, lower shoulder 38 is moved upwardly by differential screw 39 to buckle spring element 37 which has a predetermined critical buckling load. This load is transmitted upwardly against the lower end of expander 24, and its tapered surface is engaged with the tapered surface on the inside of the arms 22 to urge the arms outwardly with a substantially constant force proportional to the critical buckling load of the spring element. Subsequently, the expanding tool is passed through the liner to expand it in the casing in the manner described hereinbefore.

The foregoing description of a preferred embodiment of my invention has been given for the purpose of exemplification. It will be understood that various modifications in the details of construction will become apparent to

the artisan from the description, and, as such, these fall within the spirit and scope of my invention.

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#### I CLAIM:

- 1. A device for expanding a metallic liner inside a conduit which device comprises a shaft element, an expanding die member attached to said shaft element, said die member comprising a movable liner-forming member L positioned on said shaft and being radially movable in respect thereof to contact said liner, an expander member slidably positioned on said shaft between said shaft and said die member to move said liner-forming member from said shaft, and a constant force spring member positioned on said shaft to contact said expander member and to maintain said expander member against said liner-forming member, whereby said liner-forming member is urged against said liner by a substantially constant force.
  - 2. In a device for installing an expanded metallic liner in a conduit wherein an expanding die is moved through a liner positioned in said conduit to expand said liner: a cylindrical shaft element, an expanding die member attached to said shaft, said die member comprising a plurality of arm members disposed around said shaft and being pivotable outwardly therefrom to contact said liner, a cone member slidably positioned on said shaft between said shaft and said arm members to urge said arm members outwardly from said shaft, and a constant force spring member positioned on said shaft to contact said cone member and to maintain said cone member in contact with said arm members, whereby said arm members are urged outwardly by a substantially constant force.
  - 3. The device of Claim 2 wherein said constant force spring member comprises a plurality of columns disposed around said shaft, a first bearing plate member and a second bearing plate member, each of said bearing plate members contacting opposite ends of said columns, at least one of said bearing plate members being movably positioned on said shaft and being in contact with said cone member, stop means connected to said shaft to limit the axial travel of said movable bearing plate member along said shaft, and compression means for maintaining a lateral deflection in said columns.

- 1 4. The device of Claim 3 wherein said compression means comprises
  2 a differential screw connecting said spring member and said shaft.
- 5. The device of Claim 3 wherein said stop means comprises a

  2 sleeve-like element connected to said movable bearing plate member and

  3 slidably positioned on said shaft and a member connected to said shaft to

  4 limit the travel of said sleeve-like element.
  - 6. The device of Claim 3 wherein said columns have a rectangular cross-section, the width being greater than the thickness, and having the wider face normal to the diameter of said chaft.
  - 7. A device for installing an expanded metallic liner in a conduit which comprises a cylindrical shaft element; an expanding die member mounted on said shaft, said die member comprising a plurality of arm members disposed circumferentially around the outside of said shaft and being pivotable outwardly therefrom to contact the liner; a conical expanding member slidably positioned on said shaft between said shaft and said arm members to urge said arm members outwardly from said shaft; a plurality of slender columns, each having a long rectangular cross-section and disposed circumferentially about said shaft; an upper bearing plate member and a lower bearing plate member, each slidably positioned on said shaft and contacting opposite ends of said columns; limiting sleeves attached to each of said bearing plate members and slidably positioned on said shaft; a shoulder member on said shaft; a differential screw element connecting said shoulder and said shaft to apply a buckling load to said columns; said shoulder being engageable with the limiting sleeve connected to said lower bearing plate member, whereby the axial travel of said bearing plate members is limited; said column members transmitting their buckling load to said arm members to urge said arm members outwardly with a substantially constant force.

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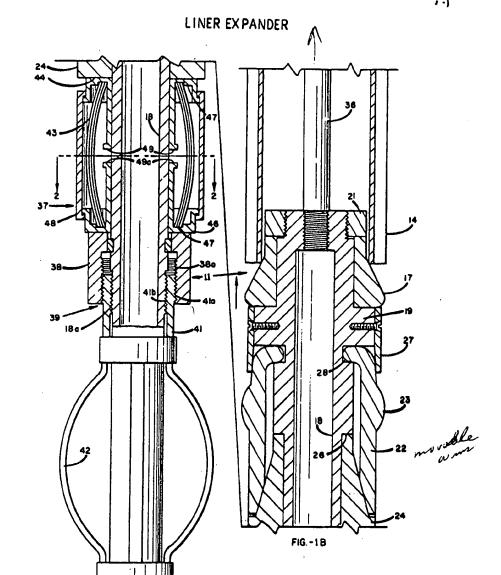
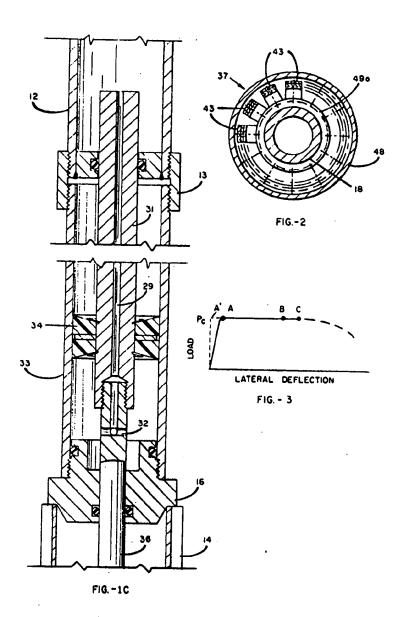


FIG.-1A



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2. In a device for installing an expended metallic liner in a conduit wherein an expending die is moved through a liner positional in said conduit to expend mid liner: a cylindrical shaft element, an expending die member attached to eaid shaft; said die member comprising a plusality of arm members disposed around said shaft and being phystable unteartly therefroe to contact said liner, a come member salidably specificmed on said shaft between said shaft and mid arm members to varyo said arm ammers consertly from said shaft, and a commant force spring member positioned on said staft to contact said once member and to mintain said once member in contact with said are members, whereby said are toolward outwardly by a substantially consented force.

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- . The device of Claim 3 wherein said compression prome comprises a differential surest equacting said apring senter and said shaft.
- 5. The device of Claim 3 wherein said step means comprises a alsowable bearing plate number and cutably goalsioned on raid shaft and a support conscuted to said shaft to limit the travel of said alsowablin alsowab.
- 6. The device of thate 3 whereis said column have a meaningniar arous-meeting, the width being greater than the thickness, and tening the wider free moved to the dissource of said shaft.
- 7. A device for installing at expended untallis liner in a comisti determined and profession and district and the special states and the special on said shaft, said the sensour comprising a planelity of are someone disposed enformatically around the outside of eald shaft and budge pluotable outearth; therefrom to content the liner; a statest expending maker slidebly positioned on said short between said short and said are employed to tops said are optimizing from suid abant; a plurality of alander columns, each bewing a long routingular ames-section and disposed streamsentially short said chaft; an upper bearing plate masher and a lower tearing plate suster, oh slikkely positioned on sale shaft and osmisative opposite order of sale mi limiting alsows ubteched to each of said bearing plate sembors and alifably positioned an each statt; a shoulder number on sand shaft; a differential screw elegant connecting said shoulder and said state to apply skiing look to suid sainman suid Choulder being supposed with the limiting miners commerced to each larger bearing plate mentur, whereby the arial treval of maid bearing plate members is limited; said column weathers branastiting their bushing load to said are assbore to urgs said and assbore estantily with a substantially constant force.

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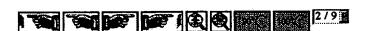
fines roots of the type mentioned above of but are employed in wells deep in the growns, it is highly preferable that a tool to meet she in tenter no circumstances will become stack in the well or usuae damage to the well. Any much trouble communing in a mall see remail to considerable loss in time and created trouble to making remains.

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My invention will be better understood by reference to the following description and the economyting drawings wherein:

Figure 24, 18 and 10, tabes together, conviltate a partial sevtional view of a preferred embodiment of a liner expending tool according to the present investion; and



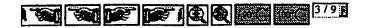


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Figure ) is a typical plot of applied lock versus Definction for the constant force spring device of the Lavention.

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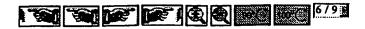




forces between the tool and the liner and the presence emerted agrines the cosing are emissioned at predetermined safe levels. The compleme force spring maker ensures that the context precents between the liner founding purion 20 of the ages 22 is great enough to provide the desired deformation of the same too whole removation desires to the sames or to the tool.

The equators force spring seasor 77 is alignly montal on the shart 18 and half between the coparating alsocat 28 and a cylindrical lower choolder seasor 38 forcing a portion of a differential screw alsocat 39 which becomes the localing on spring member 37 to chart member 18. The differential screw alsocat comprises shaft member 18 on the certific of unich are one and termeds alsocat comprises shaft member 18 on the certific of unich are one and termeds alsocat comprises shaft member 18 on the certific of the leaster, the broad with threads the end hip on the certific and the leaster, respectatively, to suggest with threads on the shaft and the shoulder. The two sets of threads are source, such as square, sudified equick, or farm threads, to witherand very high leads and differ in pitch so that shoulder 35 is seemed appearily on the shaft 18 when the shaft is revolved relative to thinkle \$1. The shoulder 36 is secured to the shaft 16 by splines \$5 so that it can alide implicationally, but it is not tree to rotate on the shaft. Finally stranded to the lower sea or the thinkle is a friction scaler, such as but thrings \$20, a hydrantically equated friction paid, or other such devise for frictionally equated friction paid, or other such devise for frictionally equated friction paid, or other such devise for frictionally except to the shaft with the secure threads 18a, e.g. right-head threads, and the pitch, or land, or except the thinkle against threads 18a, with the pitch rotate things alove to unity. In this summer, clock-vice revolution of the shaft relative to the thinkle senses shoulder sucher 35 to atvance upwerd aligntly and a compression load is americal upwardly on apring alament 37 to exceet burning. For example, one existencery threads on a chart approximately 1.7-inch certain discuster and five and inventer threads on a chart approximately 1.7-inch certain discuster and five and inventer threads on a chart approximately 1.7-inch certain approximately 2.5-inches incide dismeter.

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Constint force spring e)meant 37 comprises unions element by, sown-tageonally convirting of a plurality of alongsted solumn disposed around short 18. Upper bearing plate empirer bk is in contact with the apper ends of the solumn and is alliably positioned on shart 18 to transact the force of the spring longitudinally against the bottom and of expendes analose 9k. Lower bearing plate number 56 contacts the lower ands of the columns and is moved upwardly along the seart by language the lower ands of the column and is moved to reveal of revealing differential source alsocat 39. Grooves 17 are provided in such of the bearing plates, to form on upper seas and a lower seas, infarchish the costs of the column are inserted. These grooves may be shaped to contain with the shape of the column such it seated. A cover 18 any be employed to amplite foreign antier from the spring mechanism and to protect

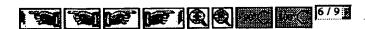
A means for limiting the deflection of the columns is required.

Although the column element functions in a buckled condition, application of proceeding ampressive lead thereto would sense total failure or repture of the columns. Therefore, a pair of stope by and the are provided for this purpose. As shown, the stope are rigidly commerced to the bearing plates, and, in affect comprise upper and lower limiting alsevas positioned on the shaft to alide longitudinally thereon. The ends of the stope may some toward, or any from, each other as the load on the squing number varies. Lower shared from moding form by lower shoulder 36 accessed to the shart 18.

Ensewer, the spacing between the sade in much as to limit the longitudinal travel of the bearing plate members as they move together to prevent permanent deformation of the column alsered to 7. The countries makes for preventing shangs to the column alsered to 7. The countries makes for preventing somethed on the chart may serve as stops, or the cover 48 provided with satisful commentions may be suplicited for this purpose to limit longitudinal and/or internal deflection of columns.

The columns of the column element 43 may be arranged errord the grant 16, which as shown here forces a partiest of the body of the spring Series, with each of the columns fitted in the recess 67. The solumns may be

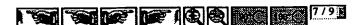
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ritied closely together as shore, or may be spared around the race, with representers used between them to meistain the desired spacing. The rember of construction. For example, the elementary ratio of the column may be warled construction. For example, the elementary ratio of the column may be warled widely, out the column make may be round, flat, first or hanged. The preferred construction is a thin, element column with tounded ands, from to now within the recess shaped to the screenists of the column ends. Materials which may be asticitated with application the screenists are contained and low alloy studie, chrowing and michal-abrondum statistics ricely, various capper have military, such as passification becomes, benyilius support, the high stabel alloys and other similar materials providing activitations support, the high stabel alloys and other similar materials providing activitations support, the high stabel alloys and other similar riceles providing activities support, the high stabel alloys and other similar riceles are of long restampator cross-contion, with the width being greater than the latchment, and accompand so that the wider face of the unisate is somethed to the dimentar of the about the activities to operation of inertia, one, outeratly may from the short 18.

For example, a group of columns 0.151-inch thick by 0.435-inch wife by 10.626-inches long, with the ends rounded, were fabricated from A.1.8.I him of the seed, quantities and draws at 775°F. Bush column was found to require a critical sumpression loading of 500 pounds in order to beoble the advant. After buckling, the columns were found to have a very flat spring characteristic, as shown in Figure 3, therein F<sub>0</sub> is the critical buckling load and point 0 represents the load and deflection at which the stress is the exhium excess the yield point of the material. Theoretically, the shape of this spring characteristic curve is described by ears 04'AlO. Actually, this curve is described by OAD due to friction in the system. Poteca A and a represent typical working limits, chich, at course, say he varied according to the application for which the spring is destigned. For example, where a large camber of flexing cycles are not emitidisted, a vorking stress just below the yield point may be used, until a sit a sentermos limit of the material of construction. In the above-marizond teats, the lateral strategies is acted to construct to the above-marizond teats, the lateral strategies is acted to construct the senterman and the stress to the above-marizond teats, the lateral strategies is acted to





approximately one true, at which the longitudinal defloration was approximately 0.225 lackes. From sere deflection to the assument deflection, the 450-pound loading was found to be substantially constant.

In emother test a spring device was built, as chose, employing 80 columns, each having a critical buckling load of 1250 posses. The interal deficient was limited between 0 and about 1.00 inches by expropriately positioning the stope. Such empressional loading, the spring element buckled at enterminally 25,000 pounds and from a longitudinal defication of 0.06 inches (making) to about 0.15 inches the load remained substantially at \$5,000

Of course, is designing a spring element as above it in advantageous to drivin the greatest possible value of longitudinal defination for specified values of laboral defination and articled buthling load, while unintending the atrees level to the columns at a safe level. The preferred columns, therefore, are laminated, so shown in Figures 13 and 2, with multiple flat understances.

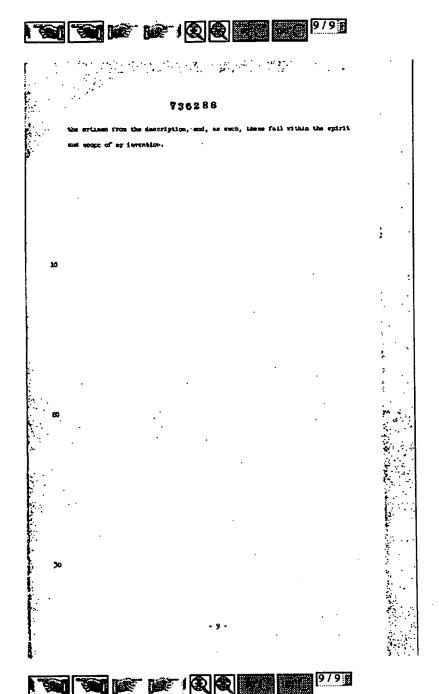
In the operation of the above expending tool for setting a liner in well exacting, the mede-up tool is lowered into the well as sectioned above, with the area 22 in the retreated position. Then the tool is at the desired level, the sail tabing is retented. The friction number by compare with the wall of the saxing and prevents thinkle 4) from revolving. With several revolutions of the tabing, lower shoulder 35 is nowed against by differential server 39 to bush the spring almost 37 which has a predeferminal critical bushing lead. This lead is transmitted against the lower and of expender 26, and the tapered surface is engaged with the tapered surface on the Laide of the error 25 to urgo the base outwardly with a substantially constant force proportional to the critical bushing load of the spring almost. Subsequently, the expending tool is passed through the liner to expend it in the casing in the seconar described hereinledone.

The foregoing description of a preferred embediment of my investion has been given for the purpose of assemblification. It will be understood that vertoos medifications in the descript of commirmation will become apparent to

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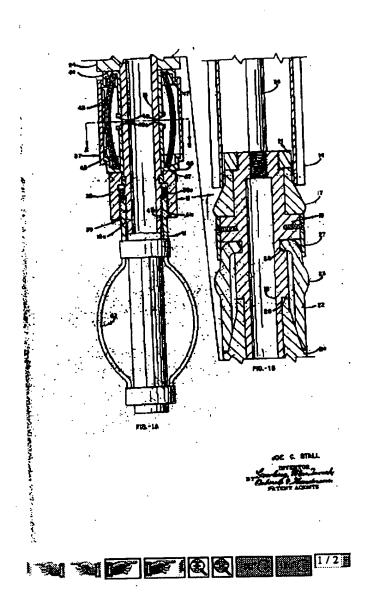
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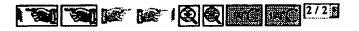


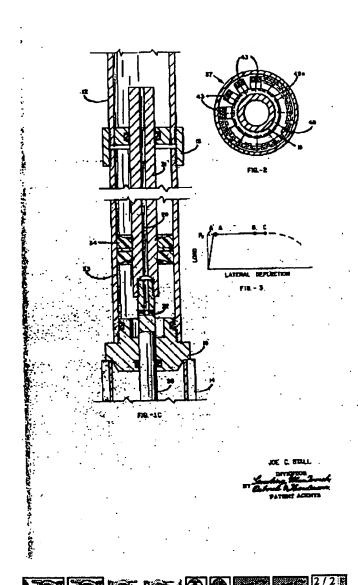




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